SEISMIC STIMULATION OF OIL PRODUCTION IN DEPLETED RESERVOIRS:

PROPOSAL SUMMARY

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SUMMARY

Anecdotal evidence from Russian and U.S. research suggests that seismic wave stimulation can have a strong influence on multiphase fluid flow through porous media. We *Beresnev & Johnson* [1994] have reviewed all available work on this subject, including over 100 Russian and U.S. technical articles and patents. This body of work supports the notion that seismic stimulation tends to improve oil mobility in fields where the oil-to-water ratio is relatively low but tends to impede oil mobility in fields where this ratio is high. However, the historical work is inconclusive and often incompletely reported. It certainly does not provide a recipe for advantageous seismic stimulation. In this project we propose to bring order and understanding to the basic question of how to use seismic wave stimulation to enhance oil recovery.

Our research will proceed in two stages. In the first stage, we will conduct exploratory research to identify and quantify the conditions and physical mechanisms under which seismic wave stimulation modifies the mobility of oil in reservoirs. We will perform laboratory measurements on a variety of rocks under a variety of conditions to determine parameters which control the response of the rock to seismic stimulation. We will also investigate, experimentally and theoretically, the roles of several physical mechanisms for fluid flow in response to seismic stimulation. In the second stage of work, if it is warranted, we will develop a methodology for in situ reservoir treatment and oversee testing in the field. The laboratory and field tests will be performed in collaboration with partners from the oil production industry. Currently, Texaco, Amoco, Marathon and Phillips Petroleum have signed on to provide support for this project. A copy of the letter of support from Phillips is included with this proposal summary.

INTRODUCTION

U.S. energy security is heavily dependent on our ability to extract as much oil as possible from domestic reservoirs. Unfortunately, the economy of producing reservoirs declines rapidly as it becomes harder to extract oil efficiently. In some cases wells are abandoned despite having yielded only a fraction of their total oil content. Existing industry methods for improving production in depleted fields are limited. We propose to study seismic wave stimulation with the goal of providing the industry with a flexible, low-cost procedure for enhancing oil recovery in depleted fields and making it economically feasible to return some abandoned wells to production.

Beresnev & Johnson [1994] reviewed over 100 journal publications, technical reports and patents dealing with acoustic wave stimulation of fluid flow in rocks. Observations over the last 30 years by Russian and U.S. investigators demonstrate that elastic wave stimulation can influence fluid flow through saturated porous media. Under certain conditions this stimulation enhances the mobility of fluids. Two potential oil field applications have arisen that exploit this phenomenon: (1) a surface Vibroseis source or downhole seismic source tool to stimulate fluid flow in underground oil reservoirs, and (2) a downhole tool using high intensity ultrasonic waves to reduce near-wellbore formation damage. Our proposed research will investigate the first of these applications.

Both natural and man-made seismic waves have been observed to cause changes in oil production rates. These observations have motivated Russian scientists to attempt artificial seismic stimulation of oil reservoirs using Vibroseis sources. The results of these stimulation experiments have been mixed, and the controlling physical parameters are not understood. A positive result (enhanced oil flow) was obtained for a depleted field in the Northern Caucasus that was subjected to a series of surface stimulations by a 20-ton vibrator (*Kuznetsov &*

Nikolaev [1990]; *Kissin* [1991]). After several days of periodic stimulation the average oil percentage of the produced fluid increased from 8–10% to approximately 20–25%. *Kuznetsov & Nikolaev* [1990] also describe an attempt to stimulate production in a well yielding almost pure oil before wave excitation was applied. In this case the oil percentage decreased significantly after several episodes of Vibroseis stimulation. These examples suggest that one of the control parameters for surface seismic stimulation is the oil to water ratio. Although the successful field tests are enticing, they do not provide a recipe for how to proceed. Based on the Russian work alone, Vibroseis treatments of depleted fields would be far too risky without further exploratory research.

Previous laboratory experiments also provide evidence of enhanced oil production due to wave stimulation.*Duhon* [1964] observed an increase in oil recovery during a water flood experiment on a sandstone sample when the sample was subjected to ultrasonic wave stimulation. Additional oil recovery during ultrasonic wave excitation above that for the conventional water flood ranged from 6.4% to 14.7%. Although these results are convincing, it is difficult to extrapolate Duhon's experimental parameters to typical field conditions as he was working with frequencies in the 1 to 5 MHz range. Also, he did not address the issue of how the initial oil-to-water ratio effects oil mobility: the initial fluid in the sandstone sample was 100% oil.

To summarize the most serious deficiencies in previous work, no quantitative laboratory experiments have been performed that address the question of how the oil-to-water ratio controls the effectiveness of elastic wave stimulation. The in-situ Vibroseis-type tests performed to date have been done in fields with poorly defined production histories and physical properties. Therefore, the resulting correlations between stimulation and oil production rates are ambiguous. We propose to confirm and quantify the roles of physical parameters in seismic stimulation of oil production through controlled laboratory research. This may lead to a seismic stimulation technology that can be successfully and routinely applied to a wide range of field conditions.

PROPOSED RESEARCH

Our work will comprise two major stages: (1) exploratory research involving laboratory stimulation experiments on typical formation rocks. (2) field demonstrations involving surface and/or downhole stimulation tests on oil reservoirs in well-characterized producing fields. Work for Stage 1 will include radial-flow experiments on meter-size samples, axial-flow experiments on centimeter-size rock samples and theoretical modeling of physical mechanisms. To complement Stage 2 work, we will compile available data on production histories and study the correlation between production rates and concurrent natural or cultural seismic activity.

Stage 1: Exploratory Research

Our goal for Stage 1 is to quantify the conditions under which fluid flow through rocks is influenced by wave excitation, determine the operative physical mechanisms responsible for flow enhancement, and devise an experimental plan to test seismic stimulation in the field. Of primary importance is to investigate the effectiveness of enhancing oil mobility for different oil-to-water ratios and wave stimulation modes. This will require experiments designed to stimulate meter-size rock samples in a bulk or volume mode.

We will measure fluid-flow response and permeability changes for oil-water mixtures pumped through rock samples in the laboratory and for simulated waterflood oil recovery, where changes in residual oil saturation will be monitored. Measurements will be made before, during, and after elastic wave stimulation, following a pre-defined matrix of possible wavefield parameters. We will quantify the effects that key experimental variables have on permeability changes. From experience we know that the key variables governing elastic wave generation and their interaction with saturated porous media include the type of source function, i.e., pulsed versus continuous wave, the source frequency, amplitude, duration of treatment, the radiation pattern of the transducers, and the method of coupling energy into the samples. The roles of other critical variables, such as the sample rock type and initial permeability, fluid-flow rate and oil-to-water ratio will also be determined.

Stage 2: Field Demonstration Tests

Based on our laboratory and theoretical results, field experiments will be planned in collaboration with our four oil company participants, who will provide the financial support for the demonstrations and will select appropriate test locations with well-characterized production histories and reservoir geologies. We expect to obtain full field support from the industry collaborators, including the use of Vibroseis trucks, downhole wireline logging engineers, technicians and a reservoir engineer who is knowledgeable of the geology and production history of the test field. We will serve primarily an advisory role in this stage of the work, although DOE support will be needed to allow continued laboratory and theoretical work to proceed as new information is obtained from the field tests. If the first year of laboratory work is promising, Phillips Petroleum will support development of a full-wavelength sonic source tool for downhole reservoir stimulation field tests. For the surface field tests, we will propose using Vibroseis trucks to stimulate a producing reservoir with seismic waves in the frequency range of 1 to 200 Hz. We cannot yet predict the appropriate mode of stimulation to be used in the field. Decisions about how many and what size trucks to use, where to apply the vibrations, and duration of treatment, etc., must await our laboratory results. Selection of an appropriate field will be based on its production history, the physical properties of the oil, the reservoir depth and proximity to available wellbores. Specifically, the field should exhibit declining production rates, based on the historical evidence, and accurate measurements of the background oil-to-water ratio must be available for a sufficiently long period of time prior to commencement of stimulation tests. The optimum target value for this ratio will be determined from the results of the laboratory work. Fields with excessively viscous produced oil should be avoided. Finally, the proximity of the reservoir to possible stimulation sources, either surface or downhole, should probably be no greater than 1000 m because the strong wave attenuation typical of oil-bearing formations will make it difficult to propagate sufficient energy to further distances.

The field experiment will be a full-scale version of our laboratory work, in which we will monitor production rates before, during and after Vibroseis treaments. In addition to the field test, we will compile available production histories for fields where detailed records of local Vibroseis activity, pump operations or other sources of seismic noise have been kept for periods of several years or more. We will search these data for correlations between wave stimulation and production changes.

EXPECTED RESULTS

Our research will provide quantitative parameters describing the conditions under which surface seismic stimulation can enhance oil recovery. The laboratory work described in Stage

1 will investigate a broad range of values for wave treatment parameters from which we can select the optimum combinations of frequency, radiated power and source duration for a given field application. This approach will be tested by applying what we learn in the laboratory to full-scale oilfield stimulation tests. If the field tests are successful, they will represent the first case histories in which reservoir stimulation has been accompanied by well-documented, quantitative measurements of field conditions, physical properties and accurate production rates. The combined results of all work completed after three years should form the basis for future industry development of the method to increase its versatility, efficiency and applicability to a wide range of differing reservoir characteristics.

The evidence presented in *Beresnev & Johnson* [1994] on the potential benefits of seismic stimulation has generated strong interest among production research scientists at several major oil companies. In addition to the potential benefits to the oil production industry, selective flow enhancement could improve on existing methods for environmental restoration of contaminated waste sites. Seismic stimulation of hydrothermal or steam reservoirs could enhance geothermal energy production. With further basic research, the measured response of fluid flow to seismic stimulation could be used as a diagnostic tool for determining unknown physical properties of dynamic systems which are difficult to characterize by other conventional methods. For instance, the excitation frequency at which enhanced flow is observed in a hypothetical system may be related to the volume of the stimulated reservoir. This in turn could allow predictions of total reservoir yield and production lifetime.

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